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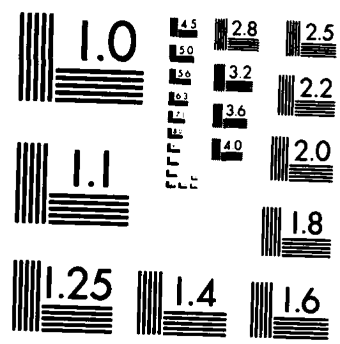

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Technical Memorandum 19-87

EFFECT OF THE M25 PROTECTIVE MASK AND HOOD ON SPEECH INTELLIGIBILITY AND VOICE LEVEL

Georges R. Garinther
David C. Hodge

September 1987
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U. S. ARMY HUMAN ENGINEERING LABORATORY
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The speech intelligibility of the M25 protective mask and hood was evaluated outdoors at distances of 1, 4, 16, and 32 meters. Computed intelligibility obtained without the use of the protective mask was compared to these results. Voice level measurements and spectral analyses were made using two different measures of voice level; articulation index computations were also performed. The subjects rated difficulty of communicating at each distance and estimated the maximum effective communication distance.

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When wearing the M25 protective mask and hood, speech intelligibility does not meet normally acceptable requirements even at 1 meter, and meets minimally acceptable requirements only at distances of up to a maximum of 12.5 meters. Mean phonetically balanced (PB) word intelligibility when wearing the protective mask and hood ranged from 70 percent at 1 meter to 20 percent at 32 meters; intelligibility computed for a no-mask condition ranged from 97 percent to 56 percent for the same distances. Based upon the intelligibility requirements of MIL-STD-1472C (DoD, 1981), the maximum distance at which minimum effective communication could take place with the protective mask and hood was 12.5 meters. The subjects' ratings of communication difficulty were similar to the objective results.

When speaking to a listener at 1 meter, the voice level was 64.7 dB(A) without the protective mask and was raised slightly to 66.2 dB(A) when wearing the protective mask and hood. Voice spectra were obtained for both the mask and no-mask conditions at 1 meter, wearing the protective mask causes a general change in character of the speech, plus an increase in low-frequency energy and a decrease in the high-frequency energy.

Computed speech intelligibility using the Articulation Index provided very good agreement with the no-mask measurements. The Articulation Index does not, however, accurately predict intelligibility when wearing a protective mask.

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ACKNOWLEDGMENT

The contributions of Dr. Joel Kalb and Mr. Wayne Anderson both with the Human Engineering Laboratory, are gratefully acknowledged for aiding in the successful completion of this study. Both assisted with the collection of the data outdoors. Also, Wayne Anderson operated the STIDAS system and analyzed the voice level data; Joel Kalb analyzed the voice spectra.

CONTENTS

TABLES

EFFECT OF THE M25 PROTECTIVE MASK AND HOOD ON SPEECH INTELLIGIBILITY AND VOICE LEVEL

INTRODUCTION

The Army presently has two types of protective masks, the M17 and M25. The M17 protective mask is intended primarily for the ground soldier; it has a special diaphragm arrangement (voicemitter) that facilitates person-to-person communication and the use of telephone handsets. By contrast, the M25 mask is primarily intended for onboard use in armored vehicles; it incorporates an internal microphone for connection to an intercom or radio system. Since the M25 does not have a voicemitter, intelligibility is reduced somewhat when speaking person to person outside the vehicle. Another difference is that the M17 mask has its filter built into the facepiece, whereas the M25 mask has a long hose with the filter at the end of it. The M25 mask, when used onboard, connects to a source of positive pressure that helps overcome breathing resistance.

Although the M25 mask is intended primarily for onboard use in armored vehicles, there are many circumstances when the mask must be worn outside. Armor personnel have to spend a considerable amount of time performing maintenance on their equipment. Dunnigan (1982) states that armor and mechanized infantry personnel spend 90 percent of their time outside their vehicles. This maintenance may take up to 8 man-hours per day. In addition, mechanized infantry personnel perform a variety of tasks such as conducting reconnaissance patrols, digging foxholes, and building bunkers, etc. During these periods, tank crews, armored personnel carrier commanders, and their drivers (the ones usually wearing the M25 mask) are often outside. The commanders, in particular, are required to issue verbal orders to their troops while wearing the M25 mask.

During CANE 1 (Combined Arms in a Nuclear Environment) in April 1983 the authors observed a tactical exercise in which mechanized infantry personnel wore protective masks and hoods intermittently over a 72-hour period, including one 12-hour period of continuous mask wear. We observed that, under field conditions involving considerable physical exertion, soldiers wearing the M17 mask were able to communicate effectively at distances of 20 to 30 meters, whereas, under similar circumstances, platoon leaders wearing the M25 mask had difficulty making themselves understood at more than a few meters. We observed that when setting up defensive positions, it was often necessary for a platoon leader to communicate at distances of up to 25 meters.

PURPOSE

In view of the mentioned difficulties, this study was conducted for the following purposes:

- to determine the extent speech communications could take place outdoors, at distances of 1, 4, 16, and 32 meters, when wearing the M25

mask and hood, under relatively ideal low background noise conditions and with minimal respiratory fatigue. (These results were compared to computed no-mask intelligibility under the same conditions.)

•to obtain an assessment from the subjects on the degree of difficulty they experienced when communicating at various distances, and their subjective assessment of the maximum distance at which reliable voice communication could be conducted.

•to measure the increase in the voice level and the change of spectrum experienced when communicating at the four test distances with the M25 mask.

METHOD AND PROCEDURE

Subjects

The subjects were nine volunteer enlisted males from the Soldier, Operator, Maintainer, Test and Evaluation (SOMTE) group at Aberdeen Proving Ground, Maryland (the consent form and test summary are in Appendix A). The subjects were tested in three groups of three each. All subjects except one had normal hearing (hearing levels of 20 dB or less at 0.5, 1, 2, and 4 kHz in both ears), as indicated in Table 1. The one exception had a level of 25 dB at 500 and 1000 Hz in his right ear, with excellent hearing at all other frequencies.

Table 1

Mean, Standard Deviation (SD), and Highest and Lowest Level (dB) of Subject Hearing Levels

	Left ear						Right ear					
Frequency (kHz)	.5	1	2	3	4	6[a]	.5	1	2	3	4	6[a]
Mean	10.5	8.3	7.5	10.0	6.6	17.2	10.5	9.4	7.7	6.6	5.0	2.7
SD	4.6	5.0	4.6	7.5	7.1	20.9	8.1	8.8	6.2	4.3	3.5	2.6
Highest level	15	15	15	20	20	60	25	25	20	15	10	5
Lowest level	0	0	-5	0	0	0	-5	0	-5	-5	-5	-5

[a]Not a screening frequency.

An attempt was made to select subjects without regional dialects, but this was not possible due to the size of the subject pool. Therefore, subjects having several different dialects were included in the subject population. Their differences in pronunciation were definitely noticeable during normal speech; however, as training progressed, these regional dialects quickly disappeared from the carrier phrase and the phonetically balanced (PB) words. It became apparent that their dialects produced a negligible effect upon the intelligibility scores achieved.

Speech Intelligibility Test and Subject Training

The standardized Phonetically Balanced (PB) Monosyllabic Word Lists (ANSI, 1960) were used in this study. These consist of 20 lists of 50 words each, with each list being phonetically balanced and of equivalent difficulty. Four randomizations of the lists were available, providing a total of 80 word lists for training and testing before starting the cycle over.

The subjects were trained for approximately 10 hours without masks, divided among four sessions. The training was conducted indoors in round-robin fashion with the subjects serving alternately as talker and listener (one talker speaking to two listeners). The listeners scored their own answer sheets (during training only) in order to familiarize themselves with the words and their spellings. The objective of this training was to acquaint the subjects with each other's voice characteristics and to achieve a plateau of listening scores of about 99 percent correct. (This level of training was not achieved by all subjects.) Test words were spoken in the carrier phrase, "Will you write --- now," with an effort made to emphasize all the words in the phrase equally. A light flashing every 4 seconds was used to control the time between the subjects' utterances.

Midway through the no-mask training of the third group of subjects we concluded that one of these subjects lacked the verbal skills required to achieve an acceptable level of performance. A substitute was found, and training started over. The replacement subject progressed to a level of performance comparable to the other subjects by the end of his fourth training session. Because the subjects served as both talker and listener in the training and testing, the two remaining subjects in the third group had six sessions of no-mask training.

The no-mask training was followed by 2 hours of training with the subjects wearing the M25 mask and hood. This training was also conducted indoors, in round-robin fashion, to familiarize the subjects with the characteristics of the talkers' voices as well as the sound of the test words when transmitted through the mask.

Outdoor Test Site and Test Procedure

Testing was conducted in a small field in a relatively quiet area of Aberdeen Proving Ground (see Figure 1). A testing azimuth was selected enabling the 32-meter maximum testing distance to be achieved with the least reflections from nearby buildings and vegetation. The talker's position and the two listeners' positions were marked on the ground with white tape.

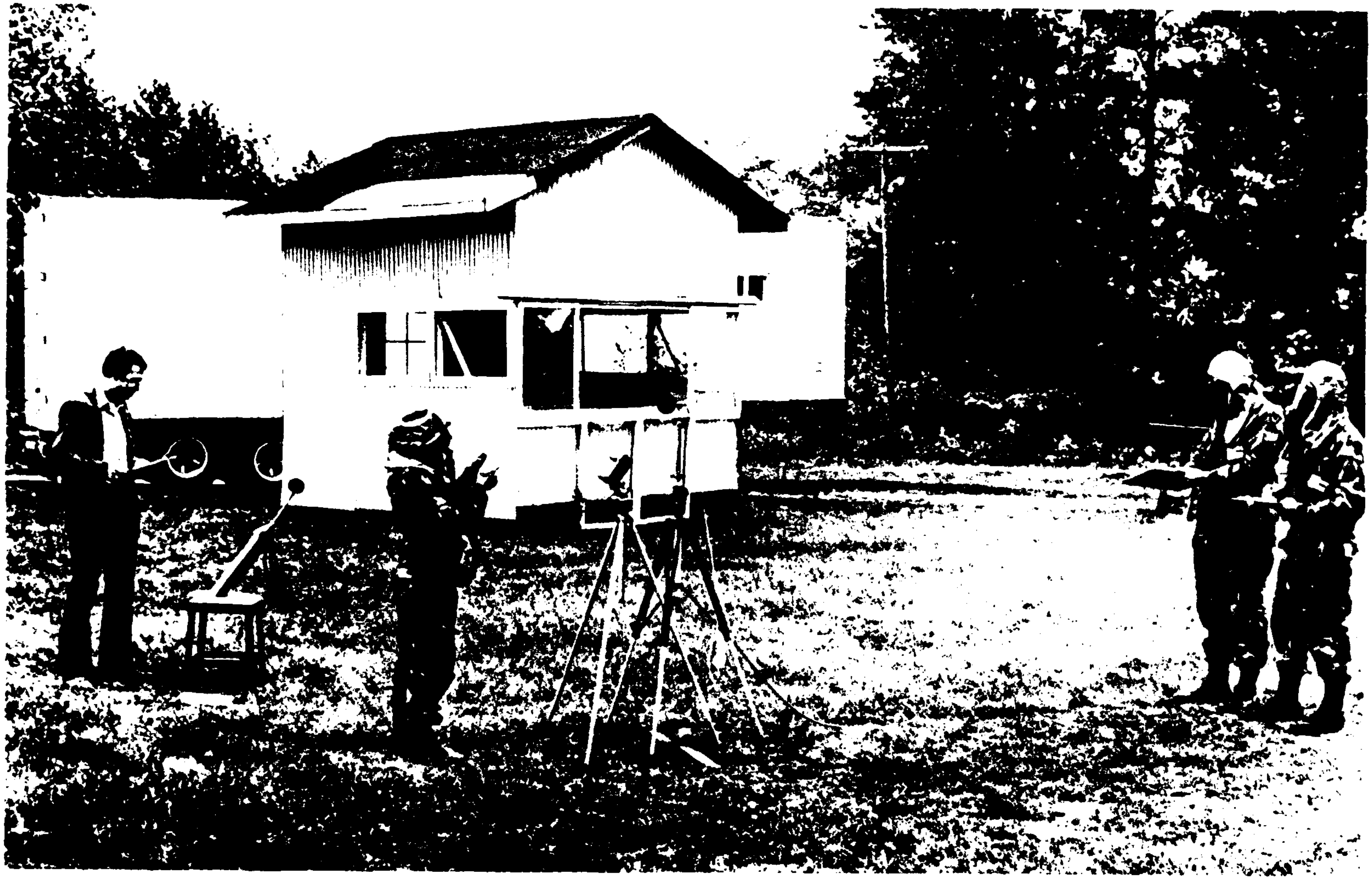

Figure 1. Test site for méasuring speech intelligibility.

A microphone was placed 1 meter from the talker's mouth to measure voice level, to record the spoken words, and to measure ambient noise.

Data collection was monitored by an experimenter positioned near the talker during testing. The words being spoken were checked for accuracy, and the background noise level was measured on a sound-level meter. Whenever transient disturbances exceeded 45 dB(A), the test would be suspended momentarily, for example, when a train passed about 600 meters away.

During all testing the subjects were instructed to use a communicating voice level. That is, they were instructed to use whatever voice level they felt was appropriate for the distance at which they were attempting to communicate.

At the conclusion of testing with the masks and hoods, the subjects read three word lists without masks so that we could measure baseline voice levels. For this test, the listeners were located at the 1-meter location.

Order of Testing for the Intelligibility Test

The purpose of the study was to gather data that would enable us to draw a graph comparing the percentage of PB-word reception to communication distance. The emphasis was on the performance of a group of subjects, rather than individual performances per se. A randomization scheme was used, with each subject being tested an equal number of times, under all conditions.

A test session consisted of a single reading by each of the three subjects (in counterbalanced order). Since there were two listeners for each talker, a total of six scores (word lists) was generated from each test session. A rest period was provided after each session.

The four communication distances were 1, 4, 16, and 32 meters. Each subject served as a talker three times at each distance, in a counterbalanced order. With three groups of three subjects, four distances, and three repetitions per distance, a total of 108 word lists was used, giving a total of 216 scores (two listeners per talker), with 54 scores being averaged for each distance.

For the first group of three subjects, the listener distances were tested in the order 1, 4, 16, 32, then the reverse, followed by the original order again. The same paradigm was used for each group of three subjects, except that the order of starting distances was counterbalanced between 1 and 32 meters.

Subjective Rating of Communication Difficulty

After the intelligibility testing was completed, the subjects participated in two assessments of communication difficulty (the questionnaire is in Appendix B). First, they rated masked communication difficulty at 1, 4, 16, and 32 meters, using a 7-point scale ranging from _easy_ (1) to _impossible_ (7).

Second, they estimated the maximum distance at which short commands could be given and received by personnel wearing M25 protective masks and hoods. This was done on a roadway adjacent to the test site that was not marked in an obvious fashion (markings were interpretable only by the experimenter). Each subject, while wearing a mask and hood and facing another person wearing a mask and hood, was individually asked to walk out to a distance that he felt was the maximum distance at which reliable masked communications, for short commands or instructions, could be conducted.

Computed Intelligibility Without Protective Mask

Intelligibility measurements were not made for the no-mask condition at 4, 16, and 32 meters. Intelligibility under the no-mask condition was computed using the Articulation Index (AI) (ANSI, 1969), and an adaptation of voice levels used by Webster and Snell (1983). First, the Articulation Index versus the distance was calculated using the idealized ANSI speech spectrum for each voice level, (i.e., normal [+0 dB], raised [+6 dB], very loud [+12 dB], and shouting [+18 dB]). The mean ambient sound pressure level at the test site was also calculated (see Table 2). These AI values were then converted to PB word intelligibility using ANSI S3.5-1969. Figure 2 shows the resulting intelligibility for the four different voice levels, at the increasing distances when talking in the test site ambient noise level.

Table 2

Ambient Sound Pressure Level (dB) at the Test Site

Group		Octave-Band Frequency (Hz)									
		63	125	250	500	1000	2000	4000	8000	SIL(4)[a]	dB(A)[b]
1	$\bar{x}$	51.8	44.2	36.1	36.8	36.3	34.1	36.9	36.5	36.0	43.0
	SD	2.8	2.5	3.2	4.8	4.3	5.2	2.9	4.1		1.9
2	$\bar{x}$	52.4	45.7	38.3	38.5	39.7	38.7	38.9	36.1	39.0	44.1
	SD	1.9	3.3	3.1	3.2	2.6	3.2	3.1	4.3		1.7
3	$\bar{x}$	57.9	50.5	39.5	37.7	35.8	30.7	27.1	26.8	32.8	41.3
	SD	2.8	4.2	3.9	5.0	3.9	2.4	2.3	3.5		3.4
$\bar{x}$		54.0	46.8	38.0	37.7	37.3	34.5	34.3	33.1	36.0	42.8
SD		2.5	3.4	3.4	4.4	3.7	3.8	2.8	4.0		2.4

Note. These findings do not include transient noises such as trains or loud vehicles occasionally passing in the distance; testing was stopped at such times.

Means ($\bar{x}$) and standard deviations (SD) are shown.

[a]SIL = Speech interference level.
[b]dB(A) = A-weighted sound level.

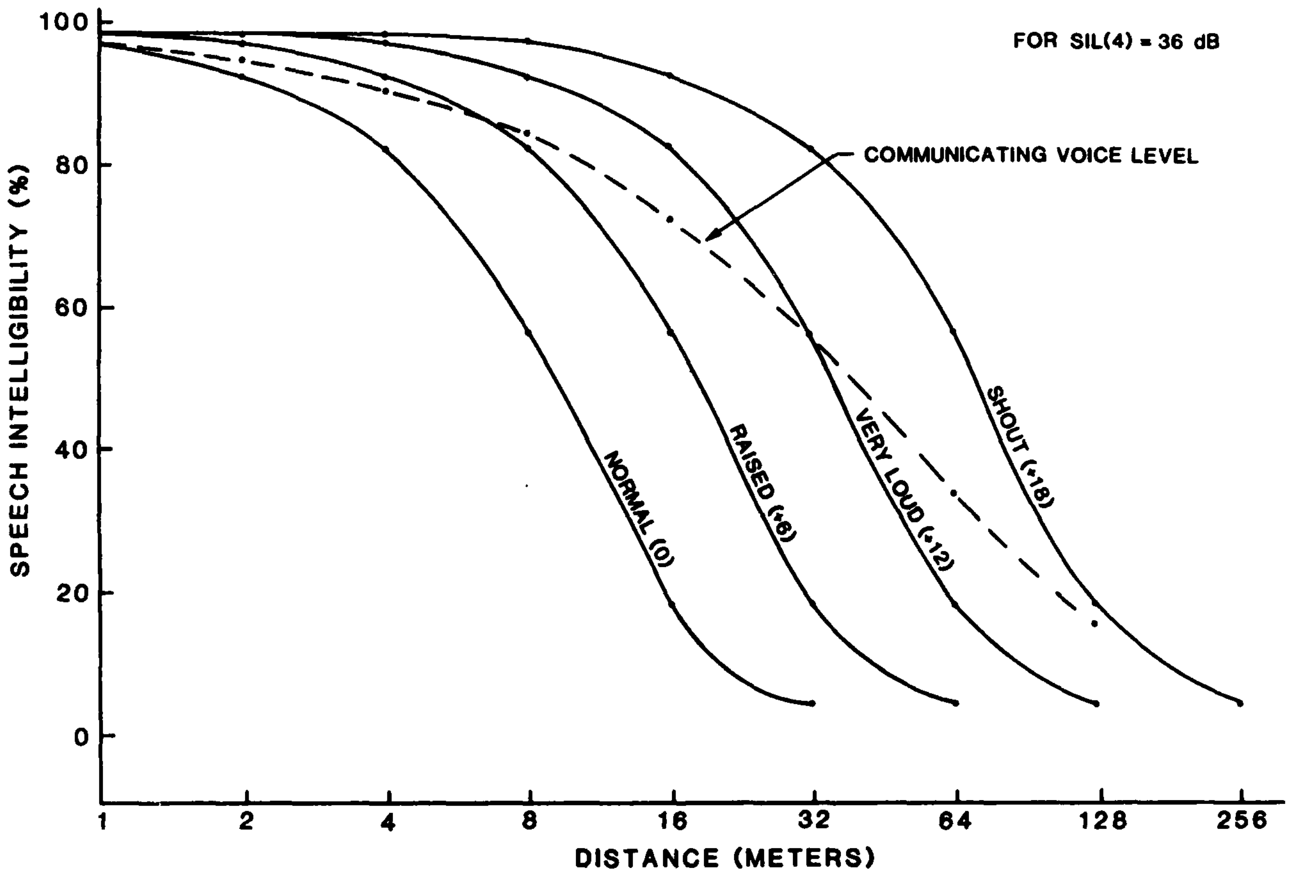

Figure 2. Computed speech intelligibility versus distance for four different voice levels and for a communicating voice level in a SIL(4) level of 36 dB.

As distances increase it is natural for talkers to compensate for the loss in signal-to-noise ratio at the listener's ear by raising their voice level. Gardner (1966) has measured the effect of distance upon voice level when individuals are conversing in free-space rooms and quiet offices. He found a 4.5 dB increase in voice level when the talker-to-listener distance increased from 3.25 feet to 12 feet. This corresponds to a 2.4 dB increase in voice level for each doubling of listener distance. This phenomenon assumes that the talker is sufficiently motivated to actually communicate with the listener rather than just talk "at" the individual with a constant voice level.

Based upon Gardner's data, a reasonable estimate of increasing voice level when using a "communicating voice" as defined by Webster and Snell (1983) outdoors, is an increase in voice level of 2.4 dB for each doubling of listener distance (6 dB). Since each vocal effort shown in Figure 2 represents a 6-dB increase in voice level, a communicating voice would increase by 0.4 of a vocal effort for each doubling of distance to the listener. The curve labeled communicating voice is therefore a reasonable estimate of the speech intelligibility obtained without the protective mask, outdoors, in the ambient level specified, for distances of 1 to 128 meters.

Instrumentation

A Brüel & Kjaer (B & K) Type 4165, 1/2-inch condenser microphone, placed 1 meter from the talker's mouth, was connected to instrumentation inside a semitrailer located approximately 35 meters from the test site (see Figure 3). Inside the trailer, the microphone was connected to a B & K Type 2604 microphone amplifier that was connected to a Nagra III tape recorder. The Nagra III tape recorder was used to make continuous recordings of the intelligibility tests in order to subsequently analyze voice level and background noise in the laboratory and to have a permanent record of the words actually spoken. During the test, the spoken words were continuously cross-checked against the word lists, and after every session (three lists) an octave-band analysis was made of the background noise level using a B & K Type 1612 band-pass filter connected to the B & K Type 2604 microphone amplifier.

Voice Level and Spectrum Level Measurements

Two different measures were used to determine the voice level, at 1 meter, when speaking through the protective mask to the individuals at the four different distances. Voice level was also measured without the mask at 1 meter when speaking to a listener at 1 meter. The methods were an A-weighted analysis and a one-third octave-band analysis using a real-time analyzer (RTA) and an A-weighted measurement using a precision sound-level meter. An additional measure using the speech transmission index device using artificial signals (STIDAS) is shown in Appendix C.

Real-Time Analyzer

The tape recorded word lists were played into a B & K Type 3347C real-time analyzer that was set on the maximum hold mode and a 200-

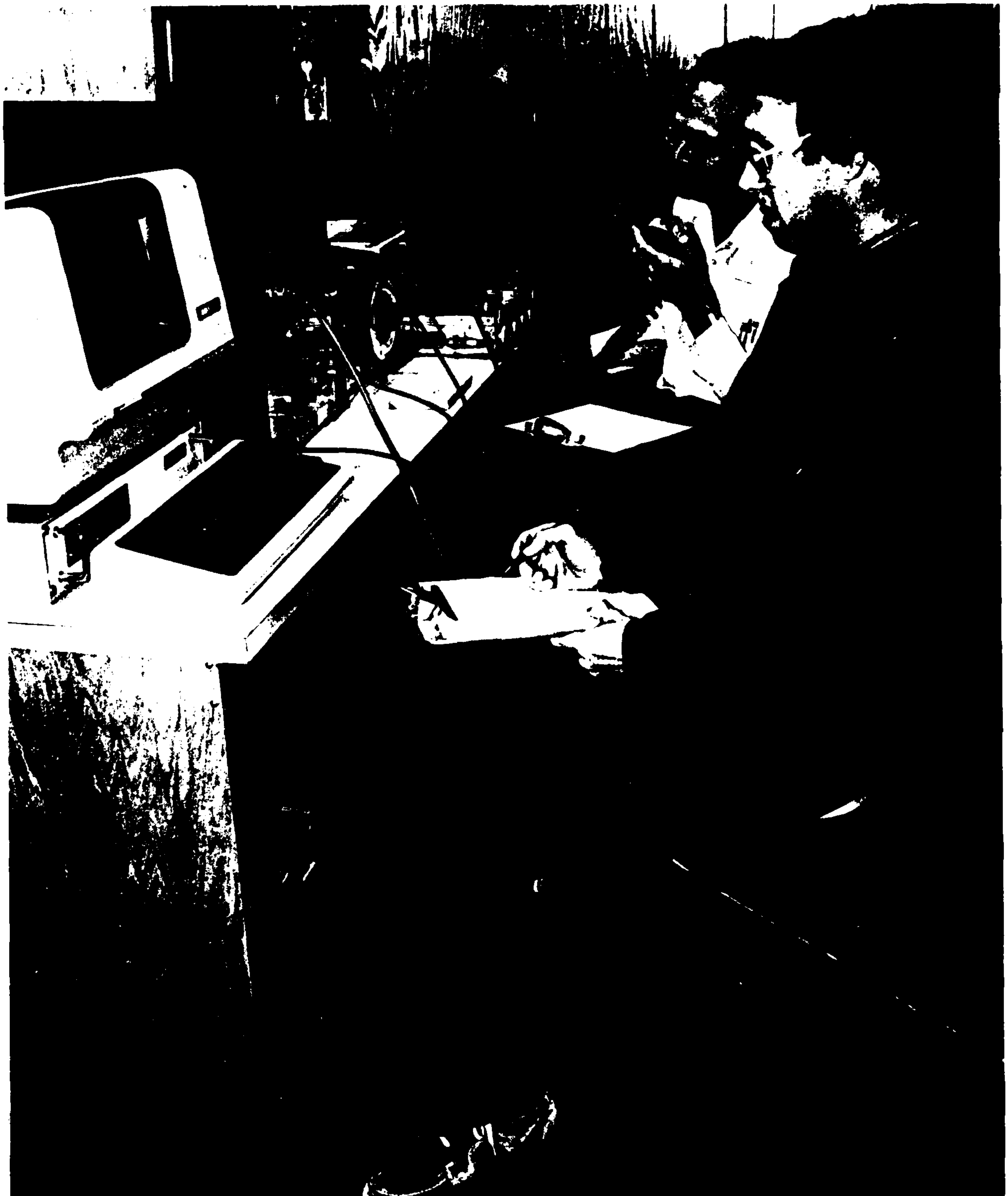

Figure 3. Instrumentation for recording speech and measuring voice level.

millisecond time constant, and was connected to a Hewlett-Packard 9845® microcomputer. The analysis of each word, including the carrier phrase, was accomplished by observing the one-third octave-band display and the A-weighted level on the RTA screen. At the moment the phrase was completed, the maximum values were stored in the computer. The values obtained were almost always due to the PB word itself. This occurred because even though the subjects were instructed not to emphasize the PB word, most of the time it was either equal to or slightly louder than the other words in the carrier phrase. The A-weighted and one-third octave-band values were then averaged for all subjects for each condition.

Sound-Level Meter

The tape recorded word lists were played into a B & K Type 2209 sound-level meter set on A-weighting and fast-meter damping (A, fast). The experimenter observed the meter deflections and recorded the maximum value of only the PB word within each of the carrier phrases. These values were then averaged for all subjects for each condition.

RESULTS

Intelligibility Training Data

Figure 4 shows the progression of the mean PB word intelligibility scores of the nine subjects for each of the no-mask training sessions. Each score is the mean of the 13 lists received in each session, with the subjects' scores being lettered A through I. The best subject started out with just above 95 percent of the words correct, while the worst subject started out with 76 percent of the words correct. The median performance for the group of nine subjects reached about 98 percent of the words correct by the fourth training session.

Following the no-mask training on the PB word intelligibility procedure, one 2-hour session of indoor training with the M25 mask and hood was conducted. As expected, the percentage of words correctly received was considerably lower than for the last no-mask session (median 71 percent; range 59-77 percent).

Intelligibility Test Data

Intelligibility scores are presented in Figure 5, showing means and standard deviations of the PB words correctly received at each distance. The highest mean intelligibility value occurred at 1 meter, of course, and was followed by a progressive decline in PB scores as the distance increased. Figure 5 also indicates the minimum PB score of 43 percent recommended by MIL-STD-1472C (DoD, 1981). The mean distance at which this PB score was achieved, when wearing the M25 protective mask, was 12.5 meters.

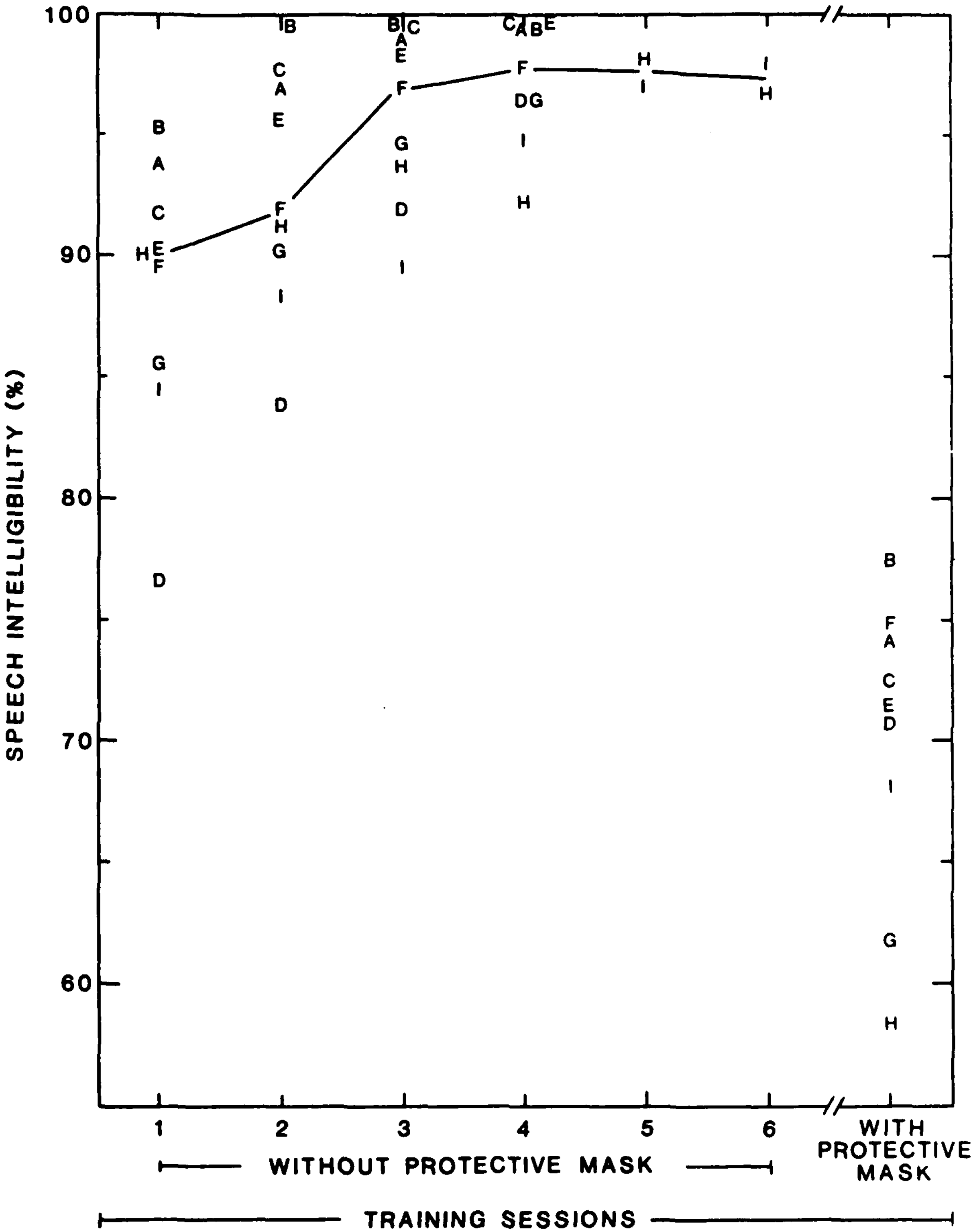

Figure 4. Median speech intelligibility progression for the nine subjects during training with and without protective mask. (Each letter indicates the speech intelligibility obtained for the six training sessions without protective mask and for the single training session with protective mask.)

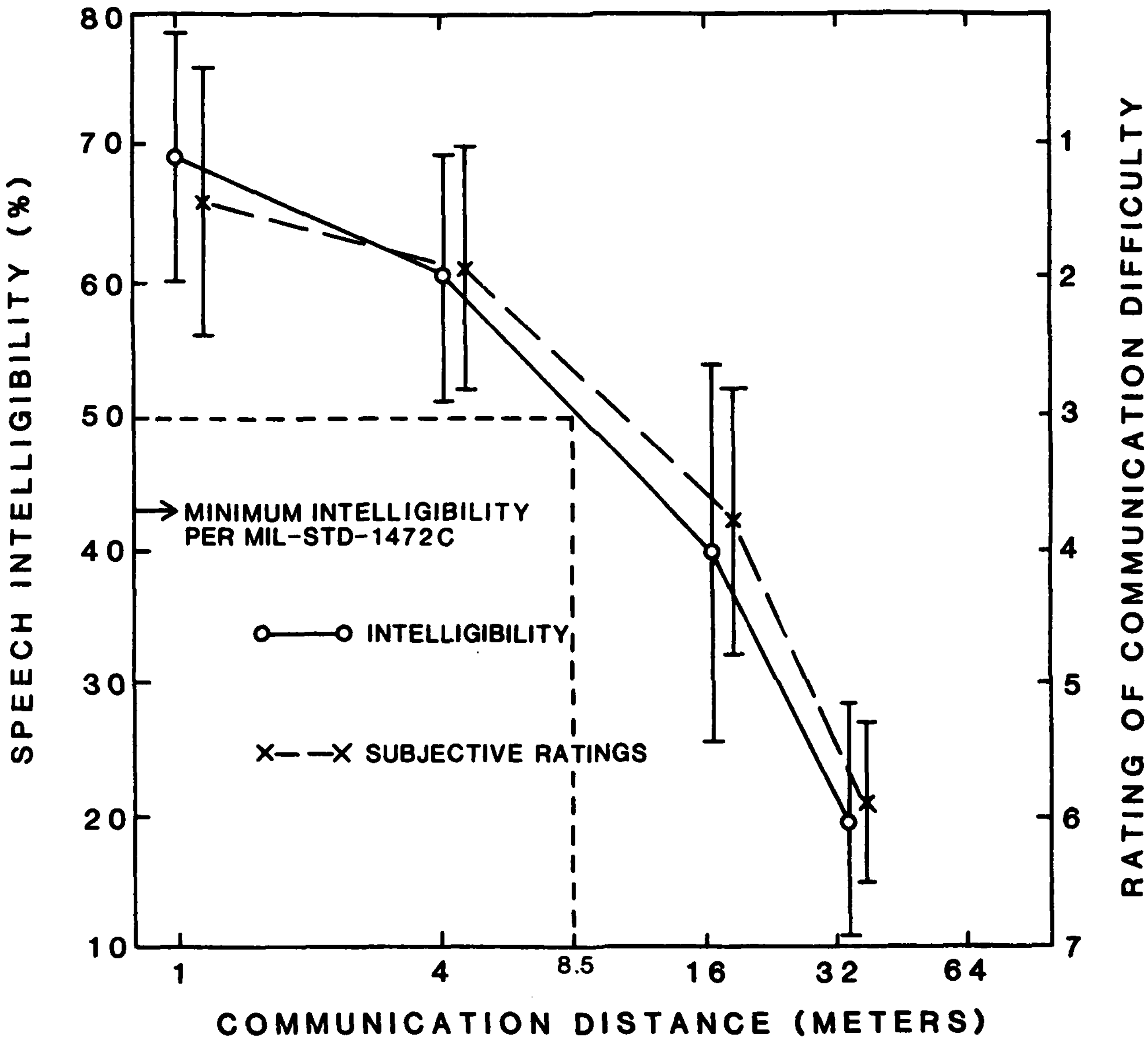

Figure 5. Speech intelligibility and subjective rating versus distance when wearing the protective mask (vertical bars indicate standard deviation).

The mean intelligibility scores achieved for each of the three groups of subjects are presented in Figure 6. This figure shows that there were some differences between the three groups due to the difficulty in obtaining volunteer subjects from the SOMTE group. The first group (subjects A, B, and C) consisted mainly of noncommissioned officers, and they provided the highest training scores in the shortest period of time. The second group (subjects D, E, and F), for which it was more difficult to obtain subjects and were of lower rank, appeared to have more trouble correctly pronouncing words and consistently scored lower as they progressed through training. The third group (subjects G, H, and I) produced the greatest problems in training and appeared to have the least education.

As previously mentioned, one of the subjects in the third group performed so poorly as a talker that he had to be replaced. This group had essentially the lowest training scores and required the longest training period to achieve a plateau. Figure 6 also shows the results of the pretest pilot study in which the experimenters determined the maximum distance at which minimal intelligibility could be achieved. This test was conducted with a minimum number of repetitions in which the untrained experimenters were their own subjects.

Subjective Rating

Communication Difficulty

Figure 5 shows the subjective ratings superimposed upon the intelligibility scores for the four distances. There is reasonable agreement between the two. The subjective curve was placed so that easy communication (1) corresponded to the best intelligibility achievable with the protective mask (70 percent), and impossible communication (7) corresponded to 10 percent speech intelligibility.

The subjects rated communication to be nearly impossible for PB scores below 20 percent and to approach being easy for scores better than 60 percent. The authors cautioned that these subjective ratings of communication difficulty are for short phrases in which the subject was permitted to raise his voice to that level necessary to communicate effectively and may not be appropriate for different sentence material and voice levels.

Maximum Communicating Distance

The subjects were also asked to estimate the maximum distance at which short instructions could be understood. The subjects' estimates ranged from 2 to 14.5 meters, with a mean of 8.5 meters. Based upon the speech intelligibility results shown in Figure 5, communicating at this distance (8.5 meters) produces 50-percent speech intelligibility. It is interesting to note that this subjective rating of minimum intelligibility corresponds closely to the minimum requirement of 43 percent stated in MIL-STD-1472C (DoD, 1981).

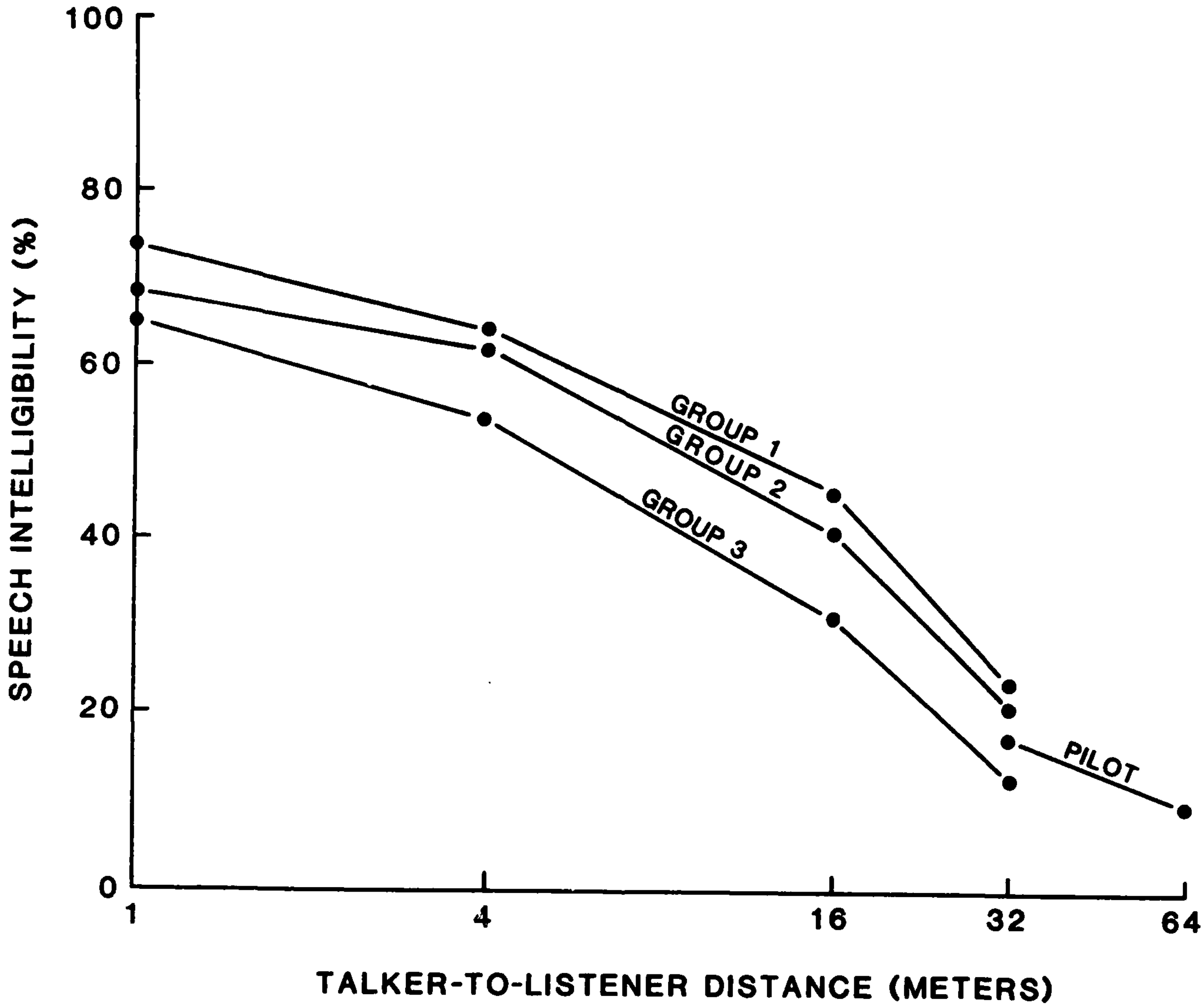

Figure 6. Speech intelligibility versus distance for each of the three groups of three subjects.

Background Noise Level

Octave-band measurements of the ambient noise at the test site were made after each session (three word list readings); on an average, these were made every 20 minutes. Table 2 presents the mean and standard deviation of these levels, along with the A-weighted sound level (dB[A]) and the speech interference level (SIL-[4]) for each of three groups of three subjects. The overall mean and standard deviation for the entire test is also shown. The mean sound level during the test was 43 dB(A) and was relatively constant throughout the several days of testing.

Voice Level

Voice levels were measured at 1 meter from the talkers when they were speaking to listeners at the four different distances. They were instructed to use the voice level that was necessary to communicate with the listener at each distance.

Figure 7 shows the increase in voice level required to communicate at the increasing distances as measured by the two different methods. The average trend of the two methods for the talkers, when wearing the protective mask, is to increase their voice level by 1.5 dB per doubling of distance (dB/DD). From 1 to 4 meters, voice level increases by a mean of 1.2 dB/DD; from 4 to 16 meters, it increases by a mean of 1.8 dB/DD; and from 16 to 32 meters, it increases by a mean of 1.5 dB/DD. This change in slope of voice level with distance is reasonable because when a listener is close, a doubling of distance would not be perceived by the talker as requiring a great increase in his voice level. At further distances the talker perceives a greater need to increase his voice level, and finally there is a distance where the talker has attained maximum vocal output. When wearing the M25 protective mask it appears that the subjects are approaching their maximum vocal output when attempting to communicate at about 32 meters.

Voice levels measured at 1 meter from the talkers, with the talkers and listeners 1 meter apart and not wearing the protective mask are also shown in Figure 7. The two measurements indicate that when talking to an individual at 1 meter with the protective mask on, the subjects increase their voice level slightly (1 to 2 dB) over the no-mask condition.

Voice Spectrum

One-third octave-band levels were determined using the same techniques as previously described under the measurements of voice level using the real-time analyzer. These spectra are shown in Figure 8 for the 1-meter position when talking through the protective mask to listeners at the 1-, 4-, 16-, and 32-meter distances. In addition, spectra were obtained when talking without a protective mask to listeners at the 1-meter position.

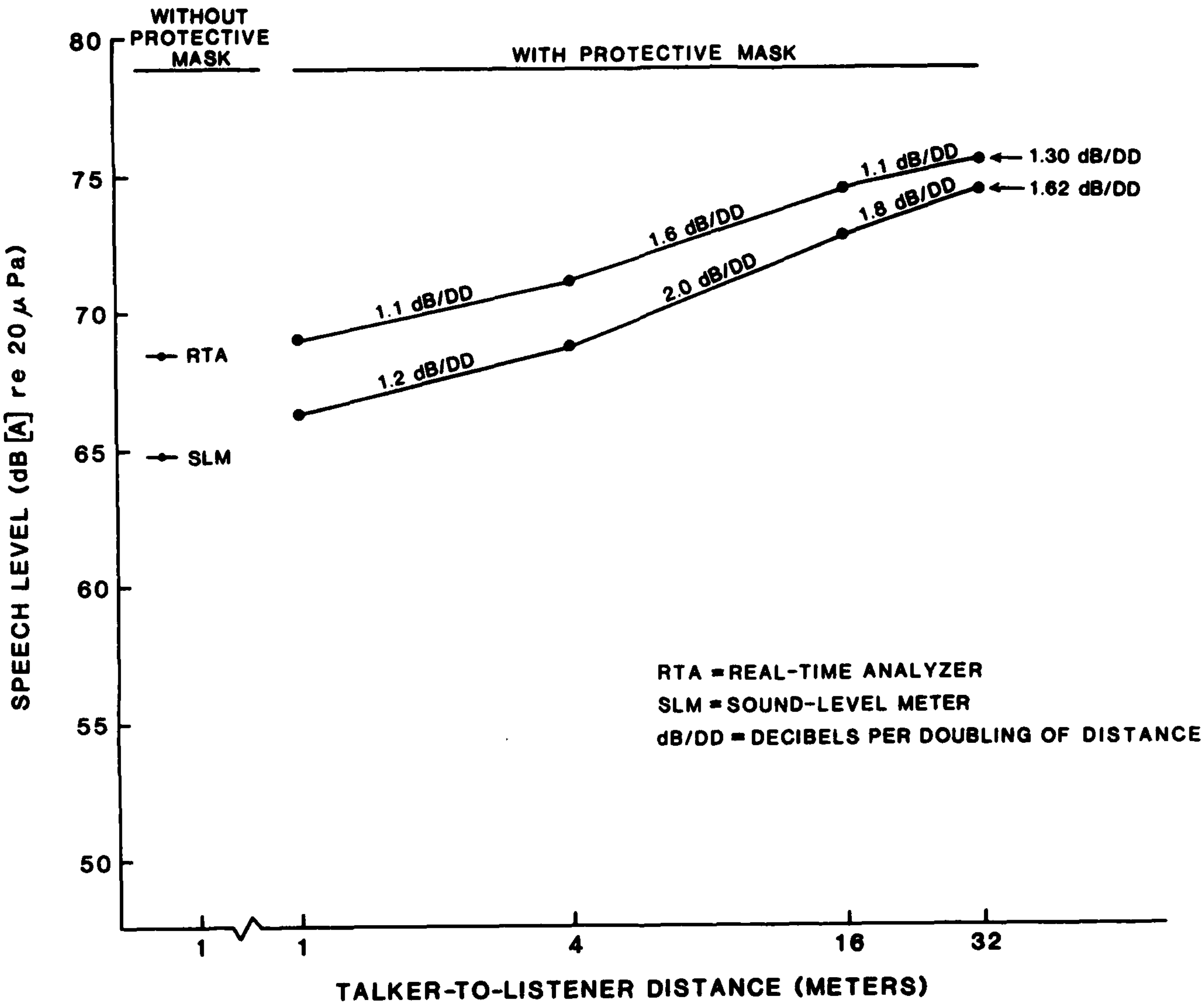

Figure 7. Voice level with protective mask for the four different listener distances measured by two different methods; also shown is the voice level at 1 meter without protective mask. The dB increase per doubling of distance is shown between measurement points and as an average.

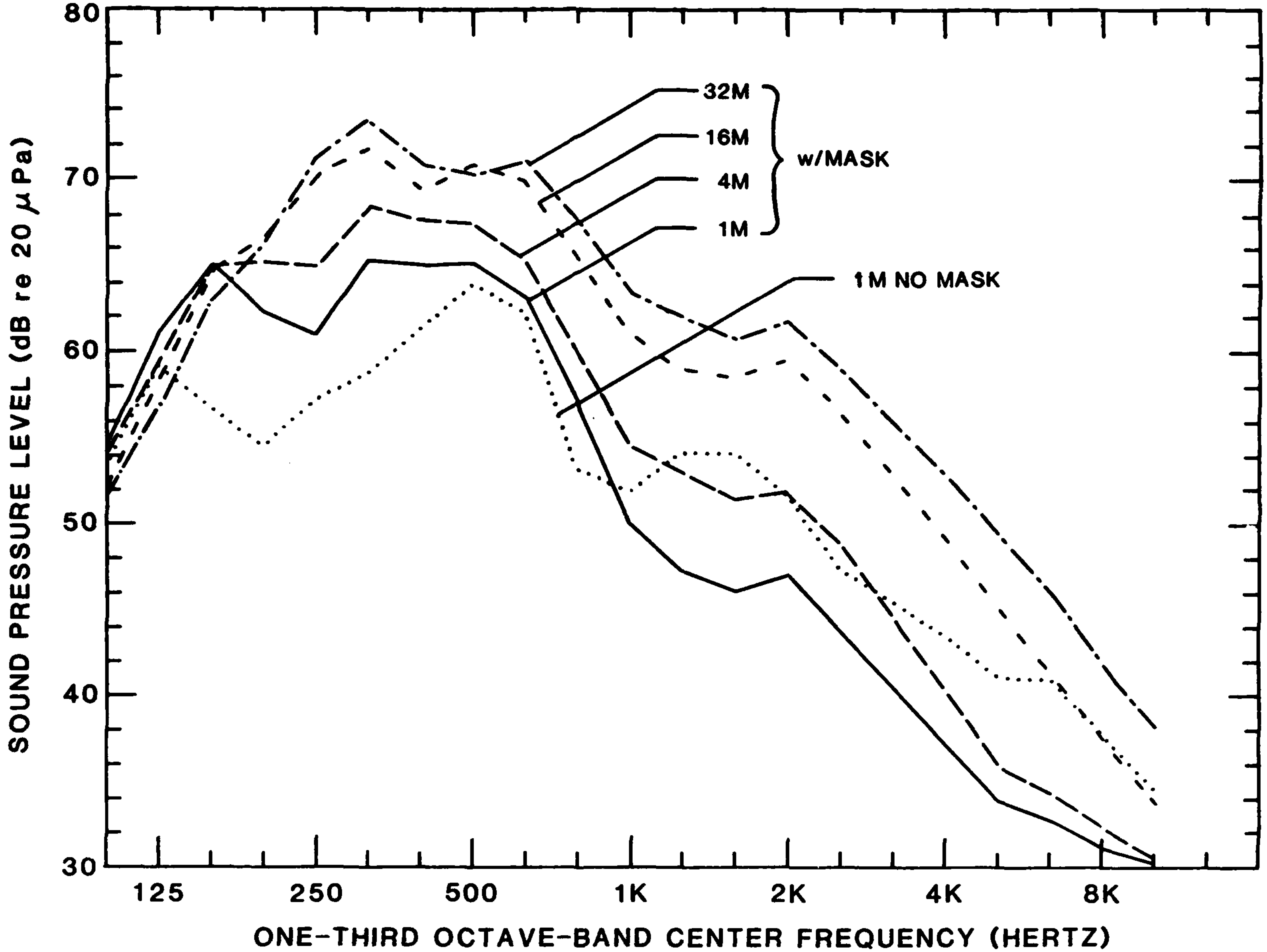

Figure 8. Voice spectrum (at 1 meter) when talking to listeners at four different distances with protective mask and when talking at 1 meter without protective mask.

DISCUSSION

Intelligibility

Measured Intelligibility with Protective Mask

We expected that intelligibility would decrease when wearing the M25 protective mask and hood, especially since the mask has no provision such as a voicemitter for person-to-person communication (Egan et al., 1943). The intelligibility tests conducted on the M25 mask indicate that communication was far from optimum even at close distances. MIL-STD-1472C (DoD, 1981) specifies that 75-percent PB intelligibility is necessary for normally acceptable communication (which corresponds to 98-percent sentence intelligibility). This Standard also specifies that 43-percent PB intelligibility is necessary for minimally acceptable communication (which corresponds to 90-percent sentence intelligibility). By comparison, the results in Figure 5 indicate that communication even at the closest distances is marginal. Specifically, when wearing the protective mask and hood, speech intelligibility does not meet normally acceptable requirements even at 1 meter, and meets minimally acceptable requirements only at distances up to a maximum of 12.5 meters. As we observed in the CANE I (Combined Arms in a Nuclear Environment) exercise, this is about one-half the distance that platoon leaders need to be able to communicate under field conditions.

In terms of operational performance when wearing the protective mask, the communication error rate using nonstandard sentences at 12.5 meters will be about 20 percent with the talker shouting at maximum vocal effort. If standard, commonly known sentences are spoken, this percentage of errors is 7 percent; and if a limited number of standardized words or commands are used, the percentage of errors will be approximately 3 percent. As mentioned, achieving these degrees of communication accuracy will require personnel to use maximum vocal effort that can be sustained only for a limited number of phrases or commands (see ANSI S3.5-1969).

Computed Intelligibility Without Protective Mask

A comparison of the intelligibility that is achievable at various distances with the protective mask (measured data) and without the protective mask (computed data) is shown in Figure 9. Here we see that wearing the protective mask causes intelligibility to decrease from 97 percent to 70 percent at 1 meter and from 56 percent to 20 percent at 32 meters. Reference to Figure 2 shows that when speaking without a protective mask, minimally acceptable intelligibility (43 percent) is possible out to 48 meters, and that the talker would almost be shouting. Also, normally acceptable intelligibility (75 percent) is achievable at a distance of 13.5 meters when approaching a very loud voice level.

Subjective Rating

The subjective ratings of communication difficulty and maximum communication distance appear to correspond very closely to the objective measures of PB word intelligibility. Although the placement of the curves in Figure 5 is somewhat arbitrary, the agreement is nonetheless clear.

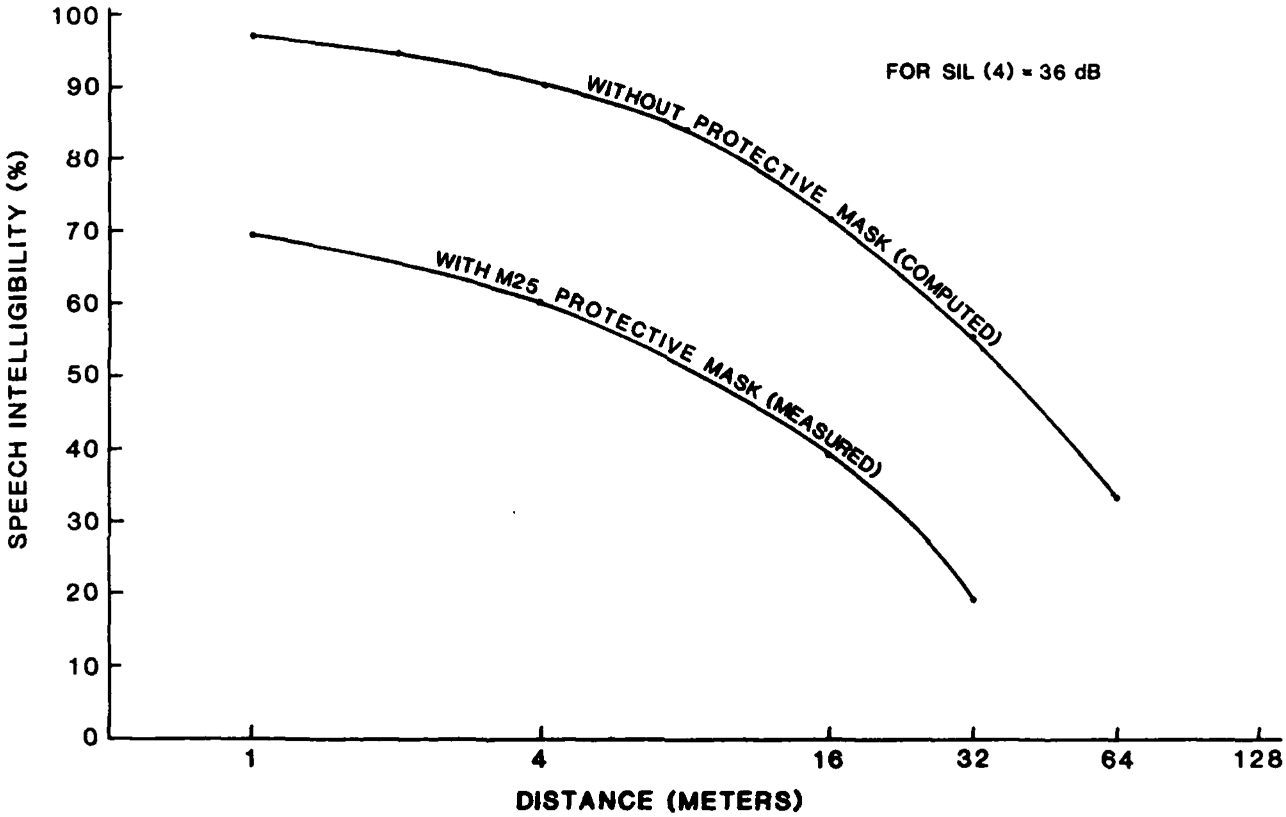

Figure 9. Computed speech intelligibility without protective mask and measured speech intelligibility with protective mask versus distance in a SIL(4) level of 36 dB.

The subjective data were obtained after the PB word testing had been completed, so the agreement between the subjective and objective data suggests that the subjects had a clear grasp of the difficulty of attempting to communicate while wearing an M25 mask and the potential impact of the M25 mask on outdoor military activities.

These results support the notion that mean subjective ratings of a group of individuals can sometimes be substituted for more objective measures, and corroborates the notion often used in human factors engineering of "asking an expert about a problem" (in this case, an experienced masked communicator). Such methods are too little used.

Voice Level

The complexity and irregular crest factor of speech (the ratio of the peak value to the root-mean-square [RMS] value) results in difficulty in accurately and consistently measuring voice level. Added problems are a result of measuring isolated words in some cases and a series of words in others, and comparing these to the relatively constant RMS level of background noise.

For comparative purposes, in this study, two different methods were used for measuring the A-weighted level of speech for each distance. As shown in Figure 7, both methods produced similar slopes, but different levels at each of the four speaking distances.

The sound-level meter produced levels that were 1.0 to 2.7 dB lower than those obtained using the real-time analyzer (RTA). This is understandable since the RTA recorded the maximum value of all words in the carrier phrase while the sound-level meter recorded only the maximum value of each PB word.

Voice Spectrum

Figure 8 shows the spectral analyses of speech when talking with the protective mask to listeners at the four distances and when talking without a protective mask to a listener at 1 meter. A comparison of the spectra shows a trend toward greater high-frequency content with increased vocal effort when speaking at greater distances; this is in agreement with the findings of Pearsons, Bennett,and Fidell (1977). A comparison of the no-mask spectrum also agrees quite well with Pearsons' et al. data, as shown in Figure 10.

It is of interest to compare the no-mask and the with-mask spectra measured at 1 meter. Although the levels for both conditions are about the same, the protective mask produces a tilting and a character change of the spectrum. As seen in Figure 8, the protective mask causes an increase in low-frequency vocal energy of about 7 dB and causes a decrease in high-frequency vocal energy of the same amount. This effect is to be expected since the protective mask wearer is talking into a closed cavity that is creating some backpressure, tending to increase low frequencies. In addition, the mask acts as an attenuator, particularly at high frequencies, thereby reducing those frequencies.

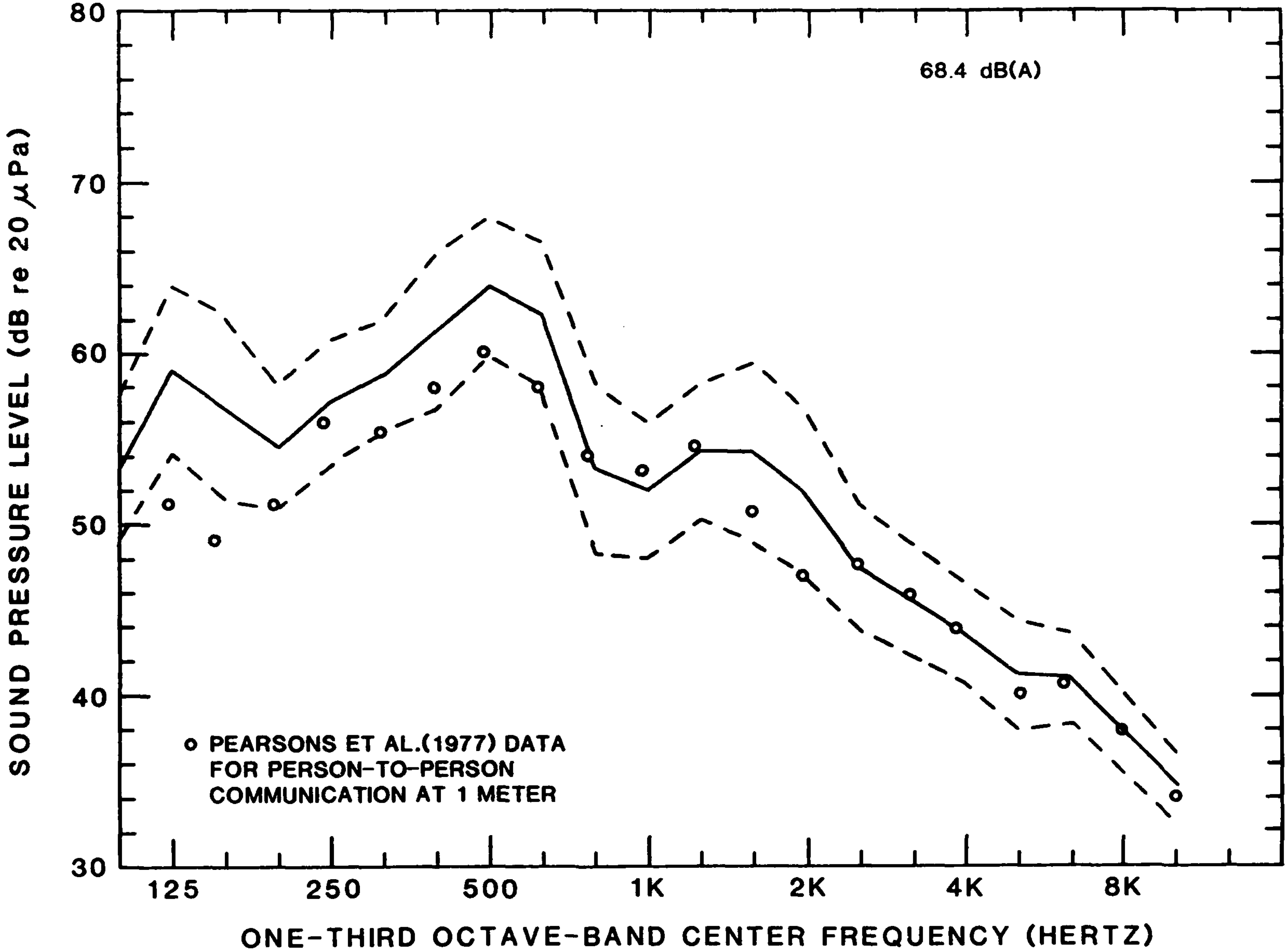

Figure 10. Measured voice spectrum for the nine subjects at 1 meter when talking to an individual at 1 meter without protective mask in comparison to Pearsons' et al. data. (Voice level is 68.4 dB[A]).

Articulation Index Computations

Computations were performed to determine if the Articulation Index provides an appropriate estimate of the intelligibility we actually obtained both with and without the protective mask. For these computations, the measured voice spectra for each listener distance were used along with the measured mean background noise level. Since all voice levels were measured at the 1-meter location, the voice levels for the 4-, 16-, and 32-meter listener locations were reduced according to the inverse square law. The computed AI values were then converted to the percentage of intelligibility using ANSI S3.5-1969.

As seen in Table 3, the no-mask computed intelligibility is close to the measured value. However, when computing the intelligibility for the with-mask condition, the results are somewhat greater than the measured values. At close listener distances this difference is quite large, while at far distances it is quite small. It is reasonable for these predicted levels to be greater than the measured levels since the AI computation has no correction provision for the speech degradation caused by the protective mask. It is also apparent that even under the best of conditions, intelligibility could not exceed 71 percent since this was the score finally achieved during training with the protective mask under ideal conditions.

Table 3

Measured Speech Intelligibility Versus Computed Speech Intelligibility Using the Articulation Index

Distance (meters)	Speech intelligibility	
	Measured	Computed
1 (no mask)	95.3	94.3
1 (with mask)	69.3	89.9
4 (with mask)	60.2	72.4
16 (with mask)	39.6	43.3
32 (with mask)	19.4	21.7

This indicates that the normal AI procedure is inappropriate for the computation of speech intelligibility when wearing the protective mask. Possible causes for this degradation are such effects as cavity resonance, backpressure, and attenuation of the protective mask, which may cause serious voice distortion.

CONCLUSIONS

• The mean intelligibility score achieved when wearing the mask and hood was 69.3 percent at 1 meter and declined to 19.4 percent at 32 meters.

• Minimally acceptable intelligibility was obtained at 12.5 meters when wearing the mask and hood; computations indicate that the same degree of intelligibility would be obtainable at 48 meters without the mask and hood.

• The subjects' estimate of the maximum distance at which short instructions could be understood was a mean of 8.5 meters.

• Subjective ratings of communication difficulty agree reasonably well with speech intelligibility scores.

• The RMS voice level (A; fast), at 1 meter from the talker, was 64.7 dB(A) without the mask and hood, and 66.2 dB(A) with the mask and hood when speaking to a listener at 1 meter.

• When wearing the protective mask and hood, subjects increased their voice level by a mean of 1.5 dB for each doubling of listener distance.

• A spectral analysis of the speech, when speaking through the protective mask at increasing distances, indicates that with greater vocal effort, high-frequency content increases more than the low-frequency content.

• The protective mask causes the voice spectrum at 1 meter to increase at low frequencies, to decrease at high frequencies, and to change in character in comparison to the no-mask condition.

• The AI computation does not accurately predict speech intelligibility when wearing the protective mask.

RECOMMENDATIONS

• Protective masks, such as the M25, that can be used outside the vehicles for which they are intended, should be equipped with a voicemitter in order to provide acceptable intelligibility.

• Subjective ratings of a communication system by a group of experienced communicators may, when appropriate, be considered as a substitute for objective intelligibility tests.

• Since the normal AI computation is inappropriate for the computation of speech intelligibility with a protective mask, a modified procedure should be developed for evaluating systems that produce such speech degradation.

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APPENDIX A

CONSENT FORM AND TEST OUTLINE

VOLUNTEER AGREEMENT

I, ____, having full capacity to consent, do hereby volunteer to participate in a research study; entitled:

Speech Intelligibility versus Distance When Wearing M25 Protective Masks under the direction of Dr. David C. Hodge and Mr. Georges R. Garinther.

The implications of my voluntary participation; the nature, duration, and purpose; the methods and means by which it is to be conducted, and the inconvenience and hazards which may reasonably be expected have been explained to me by ______________________________, and are set forth on the reverse side of this Agreement, which I have initialed. I have been given an opportunity to ask questions concerning this investigational study, and any such questions have been answered to my full and complete satisfaction.

I understand that I may at any time during the course of this study revoke my consent, and withdraw from the study without prejudice.

______________________________ ______________
Signature Date

I was present during the explanation referred to above, as well as the volunteer's opportunity for questions, and hereby witness his signature.

______________________________ ______________
Witness' Signature Date

SPEECH INTELLIGIBILITY VERSUS DISTANCE WHEN WEARING M25 PROTECTIVE MASK

This study is being conducted to find out how well soldiers can communicate when they are wearing the M25 protective mask. Specifically, we want to get data that will tell us the percentage of spoken words correctly heard at various distances between the talker and the listener. A standardized procedure will be used to collect this data; the Phonetically Balanced Monosyllabic Word Test, or "PB Word Test," is commonly used to evaluate communication systems.

The study will be conducted in two phases: the training phase will be conducted indoors in HEL's Building 520, and the testing phase will be conducted outdoors at HEL's Bullet Trap Range on the Spesutie Island Narrows near the Combat Systems Test Activity (CSTA) boat ramp. Participants will first be trained on the procedure used in PB Word Tests, without wearing protective masks. The training consists of one person, the talker, reading a word list, and the listeners writing down the key words they hear. This training will take about 8 hours and will be terminated when a near-perfect level of performance has been reached.

For the outdoor test phase, all participants will wear the M25 protective mask and hood.

During the study the participants will be trained and tested in groups of three. The outdoor phase will begin with the talker at a particular distance from the listeners. The talker will read words from a list and the listeners will write down the words they hear. After one person in a group of three has served as the talker, another one will be the talker, etc., until all three have served once as talker. Then there will be a rest period, after which the listeners will move to another location and the process will be repeated.

The location of the talker will always be fixed, but the listeners will be located at distances of 1 to 32 meters from the talker -- this will be done so we can find out the percentage of words correctly heard at various distances.

We expect that it will take about 3 days to collect the data from each group of soldiers. The test can be conducted anytime the weather is good, but tests cannot be conducted during rain, high winds, thunderstorms, etc.

We do not feel there are any unusual risks associated with this study. The most unpleasant experience you are likely to have is the increased effort it will take to talk when you are wearing the M25 protective mask. However, you will only have to talk for about 4 minutes out of every 20 minutes, with about 16 or more minutes of rest between talking assignments.

The data from this test will be used to predict communication distances for various percentages of correct word reception, and may be used to define communication doctrine in tactical situations. It will also be used to design future tests in our research programs on soldiers' performance in tactical situations. Do you have any questions?

APPENDIX B

SUBJECTIVE RATING QUESTIONNAIRE

QUESTIONNAIRE

With both you and the listener wearing an M25 protective mask, for how long a period of time do you feel that you could talk and be understood at the following distances:

1 meter________________ 32 meters________________

4 meters________________ 64 meters________________

16 meters________________

- -

With both you and the listener wearing an M25 mask, how difficult was it for you to speak loudly enough to be understood at the following distances? Use the following scale of 1-7.

easy			difficult			impossible
1	2	3	4	5	6	7

1 meter________________ 32 meters________________

4 meters________________ 64 meters________________

16 meters________________

- -

What comments do you have about the vocal effort required to speak to and be understood by an individual when both of you are wearing the M25 mask at the following distances?

1 meter____

4 meters____

16 meters____

32 meters____

64 meters____

- -

Based on your experience in this test, what comments do you have regarding voice communication while wearing the M25 mask? Please write your comments on the back of this sheet.

- -

While wearing your M25 mask would you now walk down this road to that distance at which you feel you could give short instructions (5 words) to and be understood by a soldier wearing an M25 mask standing at this location. Distance________________

APPENDIX C

VOICE LEVEL MEASUREMENT USING STIDAS

VOICE LEVEL MEASUREMENT USING STIDAS

During the intelligibility test, STIDAS (the speech transmission index device using artificial signals) was used to measure the voice level of the PB words including the carrier phrase. STIDAS, a Dutch-developed device (Steeneken & Agterhuis, 1978) being evaluated for U.S. Army applications, was used to measure voice level in real time. This device provides a method for sampling speech that produces a cumulative amplitude distribution histogram. In order to prevent the ambient sound level or silent intervals between words from influencing the measured voice level, a threshold detection method is provided that produces an A-weighted RMS level of the words only. This has the advantage of providing a voice level measure of either single words or, as in the case of this test, a measure of a series of words, STIDAS, therefore, provided the A-weighted RMS voice level of the PB words and the carrier phrase that were then averaged for all subjects for each condition. These averages are shown in Figure C-1.

Figure C-1 shows that the voice levels, as measured by STIDAS, are significantly lower than those made by either the sound-level meter or the real-time analyzer previously discussed. These differences in measured voice level are to be expected. Steeneken and Houtgast (1978) have shown that the measure of isolated words with STIDAS in 4 dB lower than that using a sound-level meter set on A, fast. The results of the present study show an additional 2.5 dB difference that is because of the fact that STIDAS, as used in the present study, produced a time-averaged level for the entire carrier phrase with its inherent quiet periods, while the sound-level meter was used to measure only the peak level of the PB words.

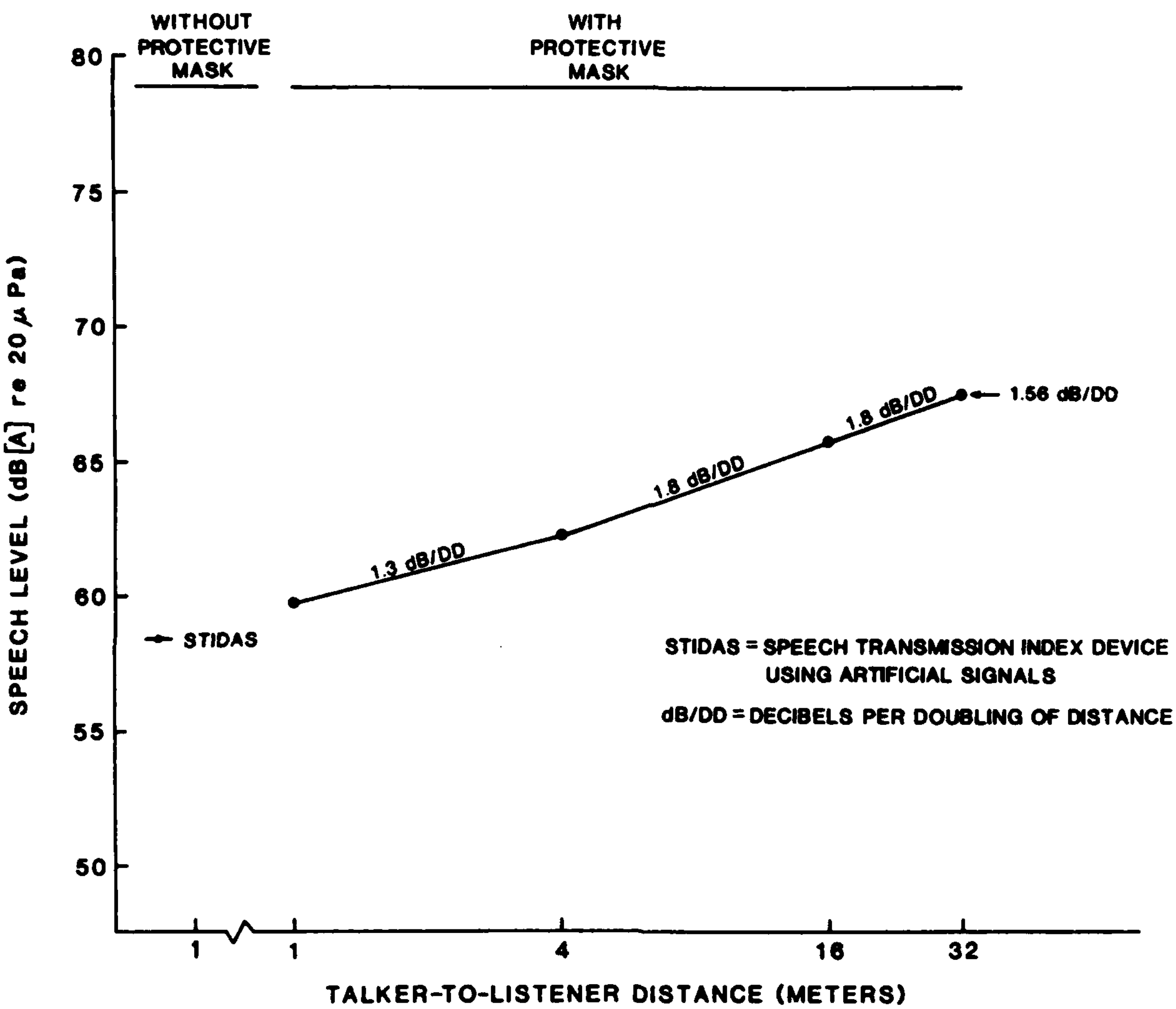

Figure C-1. Voice level with protective mask for the four different listener distances measured by STIDAS; also shown is the voice level at 1 meter without protective mask. The dB increase per doubling of distance is shown between measurement points and as an average.

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